Post Drought Changes in Residential Water Use

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DENVER WATER

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Executive Summary

Have the water consumption patterns of Denver Water's single-family customers changed over the past ten years? This and several corollary questions make up the foundation of inquiry for this project, which collected and evaluated water use patterns in a sample of approximately 100 single-family customers in the Denver Water service area. During the summer and fall of 2005 Aquacraft was hired by the Denver Water to collect water use data and update the water use analysis conducted in Denver as part of the 1999 American Water Works Association (AWWA) Residential End Uses of Water study (REUWS). The new information included updated billing data, new survey information, and two additional sets of flow trace data, which were collected at approximately the same time of year as those from the original REUWS.

These data provide important findings about how single-family water demands have changed in Denver between the mid-1990s and 2005. The results also provide data on the potential for future water conservation in Denver and the impacts of mandatory restrictions on water demands during (and after) the drought of 2002 - 2004.

To avoid confusion it must be understood that there were two data sets used for the study, and each came from a slightly different time period. The billing data, which were used to study annual indoor and outdoor uses came from 1994 and 2004, which were the years for which we had complete billing information at the time the studies were done. The flow trace data, which were used to determine household end uses of water, and penetration rates of fixtures and appliances dated from 1996 and 2005, which were the years in which Aquacraft and Denver Water conducted the data logging. This explains why in some cases the comparisons will be between 1994 and 2004 and in others they will be between 1996 and 2005.

There were two samples of customers used for the REUWS: the Q1000, which was a systematic random sample of 1000 single-family customers from the Denver Water service area, and the Q100, which was a random sub-set of 100 customers selected from the Q1000. The Q100 samples comprised the homes from which flow traces were collected in 1996 and 2005. In the REUWS it was shown from the data that the Q1000 was a representative sample of the population of single-family homes, and that the Q100 had statistically similar water use patterns to the Q1000 and was a good sample from which to draw conclusions about the single-family customers in general. A check of the new data confirmed that in 2005 these two samples remain a good representation of the single-family customers in the Denver Water service area.

Household Use

Comparing annual per household water use of the Q100 in 2004 and 1994, there was an average decrease of approximately 61 kgal per customer per year. In 1994 the Q100 single-family accounts used an average of 166 kgal, and in 2004 this fell to 105 kgal. The biggest drop in water use did not occur during the 2002, the first year of the drought, but happened in the following year, 2003. Denver Water started out in May 2002 alerting customers to the potential of a drought and requested a voluntary 10% reduction. Due the rapidly increasing severity of the situation, within a couple of months Denver Water had imposed mandatory water use restrictions. In 2003 Denver Water was in full drought mode with restrictions, enforcement, and a full publicity campaign.

Both indoor and outdoor water uses dropped significantly between 1996 and 2005. The analysis of indoor use showed a reduction of approximately 7,000 gallons per year, which represents an 11% reduction in indoor use. Indoor use dropped from 173 gpd to 154 gpd. Additional analysis indicated that 4% of this reduction was due to slight changes in the number of residents in the study homes and 7% was due to increases in efficiency of the fixtures and appliances. Highly efficient houses can use 100 gpd or less[1], so there is still significant indoor savings available for capture.

Outdoor Use

Annual outdoor use dropped between 1994 and 2004 by an average of 54 kgal, going from 102 kgal to 48 kgal. This represents a 53% reduction in outdoor use. There was very little reduction in outdoor use, however, during 2002; and the major decrease in outdoor use occurred in 2003. Not all of this reduction was likely due to Denver Water's restrictions or intentional water conservation actions by the customers since the net evapotranspiration (ET)[2] rate in 2004 was significantly lower than the net ET in 1994. Even when changes in ET are factored in, reductions in outdoor use were found. Prior to the drought the typical customer irrigated to approximately 85% of net ET, but during the first drought year (2002) this dropped to 70% of net ET, and in 2003, the average irrigation application rate dropped to 50% of net ET. In 2004 irrigation applications rebounded slightly to 55% of net ET. An important fact for drought planning is that during the drought the net ET rose, so even though the application rate dropped to 70% of net ET, the actual volume of water used for irrigation remained almost unchanged from 2001 to 2002.

It is not clear if the observed reduction in irrigation application rates are durable or will gradually rise to pre-drought levels, but an analysis of the survey results suggests that a portion of these savings may be long lasting. Out of the 79 surveys returned from the Q100, 16 customers (20%) indicated that they had made some type of permanent change to their landscape in order to reduce water use. These changes included removing sod, mulching, re-grading to eliminate runoff, installation of low water use plants, and replacing old sprinkler heads with more efficient devices. Nine customers (11%) indicated that they had made some type of temporary change, such as reducing their watering times. More customers may have made changes and failed to note them on the survey.

Penetration Rates

One goal of this project was to determine the extent to which the penetration rates of high efficiency fixtures and appliances increased between 1996 and 2005. There were significant decreases in water use for toilets, clothes washers, showers, faucets and dishwashers between 1996 and 2005. There was no change detected for baths or miscellaneous uses. Leakage in the study homes increased significantly from 1996 to 2005.

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[1] Mayer, P.W. et. al. 2002. *Great Expectations – Actual Water Savings with the Latest High-Efficiency Residential Fixtures and Appliances.* Proceedings of the Water Sources Conference 2002, Las Vegas, NV.

[2] The quantity of water transpired from plant tissues and evaporated from the surface of surrounding soild expressed as a depth of water in inches or feet (Vickers, 2001). A measurement of the water requirement for optimum plant growth based on prevailing weather conditions.

In 1996 only 6% of the study homes used ULF toilets exclusively, but by 2005 this rose to nearly 20% of the homes. This represents an increase in the penetration rate of 14% over a 9-year period, or 1.5% per year. At this uniform rate of change it will take 53 years for all of the single-family homes in Denver to use exclusively ULF toilets.

In 1996, none of the study homes had a clothes washer that used less than 25 gallons per load on average and only 3.1% of the study homes had washing machines that used 30 gallons per load or less on average. By 2005, 5.3% of the study homes had a machine that used 25 gallons per load or less and 19% had a machine that used 30 gallons per load or less. This represents a 16% increase in high efficiency machines over a 9-year period. This represents a uniform rate of change of 1.7%. The typical useful life of a clothes washer is 14 years, and new DOE standards for washers take effect in 2007. It is likely that substantially more homes in Denver will be equipped with efficient washers in the next 10 to 20 years.

The data indicate a small, but significant decrease in daily household shower use, which decreased from 34 to 29 gpd between 1996 and 2005. There was an accompanying decrease in the per shower volume and per shower flow rate, but these were not statistically significant. Overall, the data suggest that there may be a real decrease in shower usage in these homes or 5 gpd, which may be due to changes in the population, but the change is not a major one.

The situation with faucets is similar. There was a slight decrease in the household use for faucets of 3 gallons per day while the average flow rate of the faucets dropped by approximately 0.1 gpm.

Dishwashers in Denver appear to be getting more efficient. In 1996 the average dishwasher used 10.4 gallons per load. This dropped to 7.9 gallons per load in 2005 causing a corresponding 28% decrease in water use for automatic dishwashing. Household dishwashing use dropped by 0.9 gallons per day.

Leakage in the study houses rose by 8.4 gpd between 1996 and 2005, rising from 16.1 to 24.5 gpd. It is difficult to say precisely why this occurred. Leakage tends to be random and unpredictable, and it is difficult to identify the exact source of the leaks. There is water meter technology capable of informing occupants of the potential presence of leaks by indicating that constant or unusual flows were present over night (when there is typically little or no water use). If these devices were installed on a broad basis, it is possible that the leakage rates could be lowered.

Analysis of Daily Irrigation During Data Collection Period

By combining information on the irrigated areas of the homes with ET data and the results from the data logging during the summer of 2005, irrigation practices of the customers were explained to a level of detail usually not possible to obtain. The study homes had landscapes that had an average water requirement of 106% of the net ET rate. This means that when the different plant materials and irrigation efficiencies are taken into account, the landscapes would require 106% of the net ET to meet their full theoretical requirements. The study participants applied an average of only 41% of the theoretical requirements. This includes many customers that had essentially stopped irrigating completely. Well over half the study homes used 30% or less of the theoretical requirement. About 10% of the homes had no irrigation at all during the logging period. Only 8 of the study homes used more than 100% of the theoretical requirement during the logging period.

The overall implication of this result is that a substantial majority of the single-family homes in Denver are using significantly less water than their landscapes might require for full health and growth. In reality, many landscapes look acceptable even when they receive only 50% of the theoretical requirement. All of this indicates that the customers are able to maintain reasonable landscapes at a much lower percentage of ET than has been previously thought, and that in fact they were doing so in 2005, three years after the drought.

Summary and Conclusions

The following points are some of the key findings of this research project.

- The study sample from the Residential End Uses of Water study remains representative of the Denver Water single-family detached customer base at least in terms of average annual water use.
- Average per household use (indoor and outdoor combined) decreased by 37% from 166 kgal to 105 kgal between 1994 and 2004. Both indoor and outdoor use decreased during this time period.
- The largest annual decrease in water use occurred in 2003.
- Indoor use decreased by an average of 7 kgal (11%) per customer per year. Approximately 4% of this decrease was due to changes in demographics and 7% was due to efficient fixtures and appliances.
- Substantial indoor conservation potential remains. Indoor use reductions can (and likely will) be achieved by Denver Water's single-family customers in the coming 10 to 20 years.
- Outdoor use decreased by an average of 53% between 1994 and 2004. The largest decrease was observed in 2003.
- Some of the reductions in outdoor use are the result of drought restrictions and pricing measures. However, the declining trend in outdoor water use appears to be related to weather patterns as well.
- Prior to the drought of 2002 - 2004 the customers in the study applied an average of approximately 85% of net ET to their landscapes. In 2004, these customers applied 55% of net ET.
- It is not clear if the observed reduction in irrigation application rates are durable or will gradually rise to pre-drought levels, but an analysis of the survey results suggests that a portion of these savings may be long lasting.

Post Drought Changes In Residential Water Use

A Study of the Denver REUWS Sample and Comparison of Usage Patterns Between 1996 and 2005

FINAL REPORT

Introduction

Have the water consumption patterns of Denver Water's single-family customers changed over the past ten years? This and several corollary questions make up the foundation of inquiry for this project which collected and evaluated water use patterns in a sample of approximately 100 single-family customers in the Denver Water service area. The sample used for this study consisted of homes from Denver that were previously included in the American Water Works Association (AWWA) Residential End Uses of Water Study (REUWS) (Mayer, et. al. 1999). By collecting data from the same set of homes in 2005, Denver Water hoped to compare the current water use to that observed in 1996, and to examine changes in water use patterns and water using fixtures and appliances that have been effected.

Aquacraft, Inc. Water Engineering and Management of Boulder, Colorado – the lead research firm for the Residential End Uses of Water Study - was hired by Denver Water to perform the research. Denver Water Conservation Specialist David Allen served as project manager on this project. Mr. Allen also played an important role in the REUWS project and is familiar with the data collection methods and general research techniques used for both studies.

Throughout this report whenever tests are done to verify the statistical significance of a change in mean values between two measurements these will be done to the 95% confidence level using a z-test for two sample means with a null hypothesis that the difference in means is 0. Therefore, whenever the statement is made that a change in an observed value *is* statistically significant, one can read this as "statistically significant at the 95% confidence level".

Analysis of Billing Data

The first tasks in this study were to obtain and evaluate historic billing data from the samples of Denver Water customers studied as part of the Residential End Uses of Water study (REUWS) (Mayer et. al.1999). Two samples were selected as part of the REUWS – (1) the Q1000 – a systematic random sample of 1,000 single-family Denver Water customers; and (2) the Q100 – a randomly selected sub-sample of 100 homes chosen to participate in the data logging portion of the REUWS.

The specific analyses were to:

- Compare recent water use in the Q1000 with the 1994 billing data that was provided by Denver Water for the REUWS.
- Evaluate changes in water use (indoor and outdoor) in the Q1000 over time.

- Compare water use patterns of the Q1000 with the smaller sub-sample of 100 single-family homes (Q100) selected for the data logging component of the REUWS and the current 2005 end use study.
- Determine if the Q100 remains an adequate sample group for monitoring water use in the Denver single-family sector.

Q1000

> The water use patterns of the Q1000 and the population have remained virtually identical suggesting that this sample offers an accurate representation of single-family residential demand in Denver over time.

As part of the Residential End Uses of Water study (REUWS), a systematic random sample of 1000 single-family residential customers was selected from the population of single-family accounts at Denver Water. At the time (1996) the water use characteristics of this sample were found to be statistically similar to the population of single-family customers in the Denver Water service area. Similar comparisons were made by David Allen in 2005 and the water use patterns of the Q1000 and the population have remained virtually identical. This suggests that this sample offers an accurate representation of single-family residential demand in Denver over time.

Denver water provided Aquacraft with consumption data for this sample for the years 2000 – 2004. This was combined with the REUWS billing data, which was from 1994.

Q100

A sub-sample of 100 single-family homes was selected from the Q1000 as part of the REUWS. This sample became the group of homes studied as part of the data logger evaluation portion of the REUWS. The same sample was studied again in 2005 as part of the Denver Re-log study.

Figure 1 compares the average annual water use of the Q1000 sample and the Q100 sub-sample over a six year period: 1994, 2000-2004. Here it can be seen that water use in these two groups is similar. The Q100 tended to have slightly higher average demands (except for 2001), but this is primarily due to the fact that a number of customers in the Q1000 have little or no water use during a particular year. A statistical comparison test found no statistically significant difference between the 2004 water use of the Q1000 group and the Q100 group.

Figure 1 shows that total annual water use held constant from 1994 through 2000, but that in 2001 residential demand in Denver began to decline. In 2002 - 2004 Colorado was hit with a significant drought event. Denver water imposed watering restrictions, implemented more aggressive conservation programs, and eventually imposed drought surcharges on customers who did not conserve in response to this drought. Demand decreased in 2002, but it decreased more steeply in 2003 and then continued to decrease in 2004. Average annual water use for the Q1000 in 2004 declined 36.7 percent from what it was in 2000. Water use in the Q100 sub-sample declined by 36.1 percent over the same period of time.

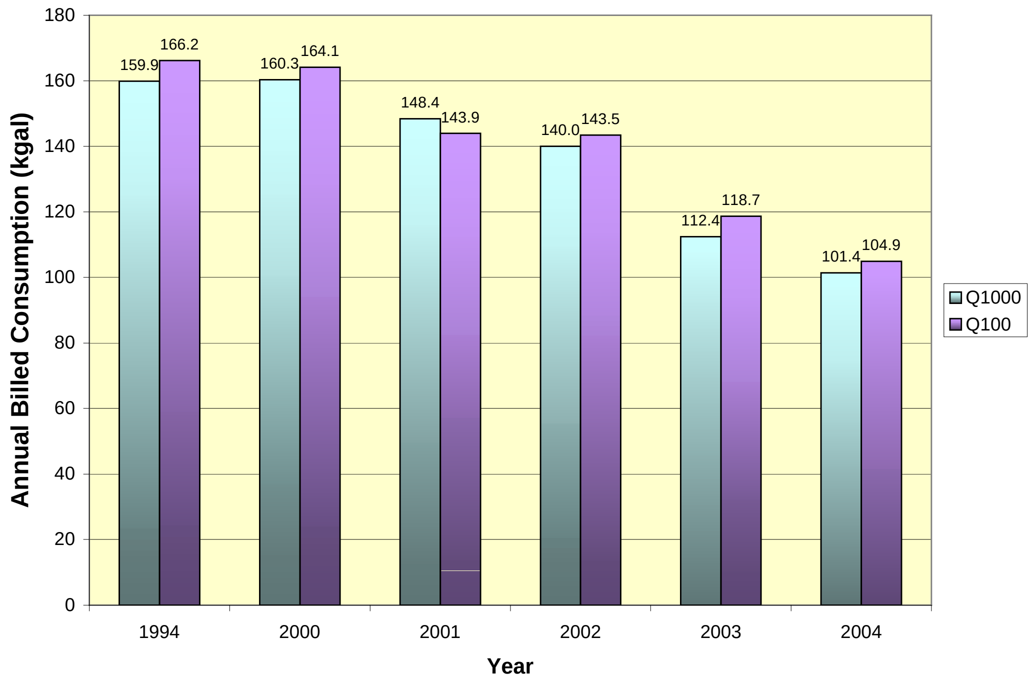


Figure 1: Average annual water use comparison, Q1000 and Q100

Figure 2 shows the average annual indoor water use for the Q1000 over the same period of time (1994, 2000-2004). Indoor use was calculated using the average winter consumption or minimum period billing as the estimate for indoor use. Here it can be seen that indoor use has declined steadily from 2000 through 2004. Single-family indoor use in 2004 was 21.4% lower in 2004 than in was in 2000. Most of the decrease came in 2002 and 2003. From 2003 to 2004, indoor use declined only very slightly suggesting that much of the savings had already been accomplished. It is not clear from these data whether the decrease in indoor use is due to widespread retrofits, leak repair, or simply changes in customer habits.

Average annual outdoor use of the Q1000 is shown in shown in Figure 3 along with Net ET on a second y-axis. The ET data were obtained from the NOAA Denver WSO weather station, which provides a continuous climate record dating from 1949 to the present. ET rates were calculated using the Blaney-Criddle formula. The drought years of 2002 – 2004 have been highlighted.

Significant changes in outdoor use are apparent in this figure. Outdoor water use dropped from 1994, 2000, and 2001 along with the net ET. However, in 2002, while the net ET increased significantly the outdoor water use stayed nearly the same. It appears that the drought restrictions prevented a rise in outdoor use that would be expected due to the increase in ET, but did not achieve a reduction in use until the following year. Overall, single-family residential outdoor use in Denver declined by 46.3 percent between 2000 and 2004. Denver water imposed strict watering restrictions during the summer of 2002, which continued with some revisions until the summer of 2004. Drought Surcharges were also imposed during the time period covered in Figure 3. Clearly some of the reductions shown here are the result of these restrictions and pricing measures. However, the declining trend in outdoor water use appears to be related to weather patterns as well.

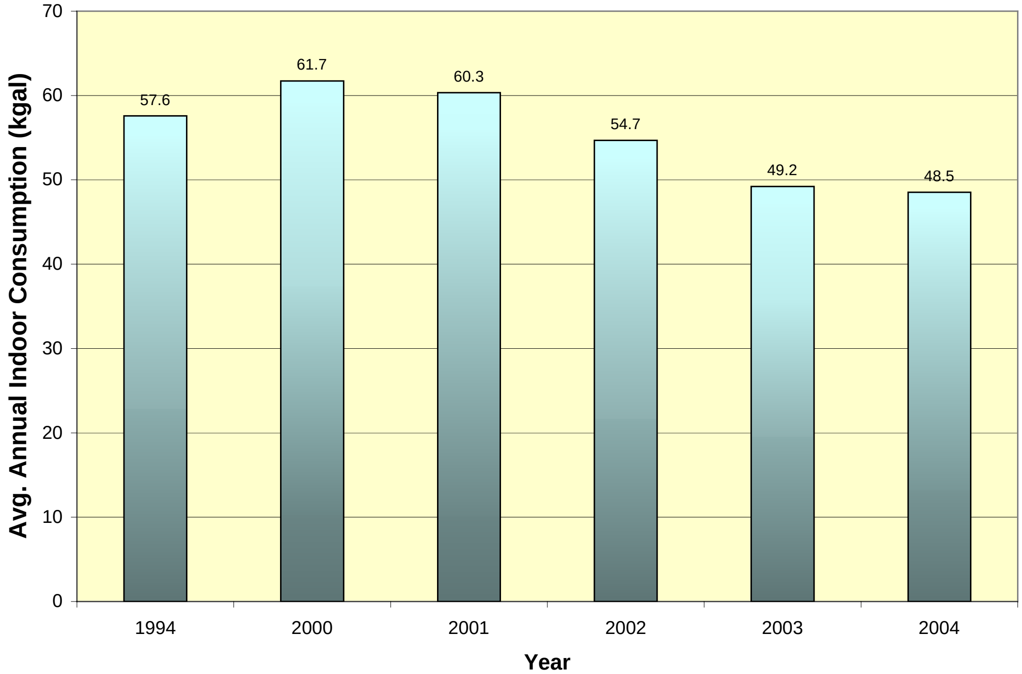


Figure 2: Average annual indoor water use, Q1000

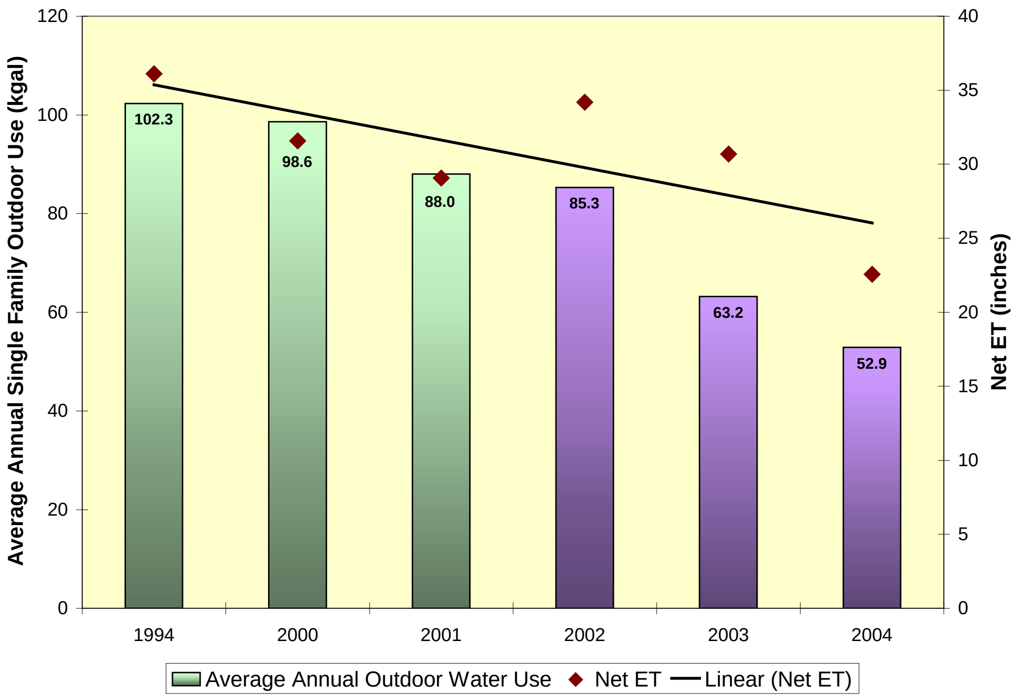


Figure 3: Average annual outdoor water use and Net ET, Q1000

Results from this analysis show that both the Q1000 and the Q100 logging sample remain representative samples of the Denver Water single-family residential customer base. This is an important finding for this project since end use data from the Q100 logging sample will be used to evaluate where the changes in water use have occurred. It appears that these results can be reasonably extrapolated to the larger population of single-family customers in Denver.

An analysis of the recent historic use patterns of these groups reveals significant reductions in water use that began in 2001 (a relatively hot and dry year), *before* the drought of 2002 - 2004. Prior to 2000 it appears that water use was fairly consistent. Demand reductions occurred in both indoor and outdoor use, but higher reductions are apparent in outdoor demand. More detailed analysis of changes in indoor and outdoor use are discussed in the remainder of this report.

Data Logging Effort

To obtain daily use data loggers were installed on the homes in two distinct seasonal periods during the summer and the fall/winter of 2005. During the summer, data were collected from June 1 – July 25, 2005. A total of 93 houses were successfully logged out of the 100 home sample[3]. An average of 13.8 days of flow trace data were obtained from the sample of 93 homes, which indicates that a full two weeks of data were obtained from nearly all the sample. During the winter, data were collected from October 3– November 24, 2005. A total of 96 homes were successfully logged out of the 100 home sample. An average of 13.6 days of flow trace data were obtained during the fall/winter period.

All flow trace data were analyzed using Aquacraft's Trace Wizard software and flows were disaggregated into specific end uses using the same methodology employed in the REUWS. The resulting end use data were placed into an Access database for analysis purposes. All data were provided to Denver Water on a CD-ROM at the conclusion of the study.

Analysis Results

A wide variety of analyses can be completed using the data collected in this study. For this report these analyses were focused on answering the key research question: Have the water consumption patterns of Denver Water's single-family customers changed over the past ten years? If so how have they changed and where have the changes occurred?

As discussed earlier in the analysis of historic billing consumption data, there have been significant reductions in water use among Denver Water's single-family customers that began in 2001 *before* the drought of 2002 - 2004. Prior to 2000 it appears that water use was fairly consistent. Demand reductions occurred in both indoor and outdoor use, but higher reductions are apparent in outdoor demand. The subsequent portions of this report will examine these changes in water use and will present comparisons of household demands between the 1996 and 2005 data collection periods. Because the Q100 logging sample remains representative of the overall water use patterns of Denver Water's single-family customers, this research provides unique insight into changes in usage patterns over time.

[3] Four homes were vacant and there were three logger failures.

Daily Household Use

In the 1996 REUWS research, detailed information about the number and ages of residents in each house was obtained through a mail survey. In the 2005 study this information could not be obtained for all participants. Consequently it made sense to base the analysis on total household use for the entire data set, and perform per capita analyses on only those houses for which population information was available.

Daily per household water use declined both indoors and outdoors between 1996 and 2005. Results are shown in Table 1. Total household water use declined by nearly 30% from 491 gpd to 389 gpd. Indoor use declined by 11 percent from 173 gpd to 154 gpd. This reduction totals nearly 7,000 gallons per household per year. All reductions in household water use shown in Table 1 were statistically significant for the paired household data is shown, although, as will be discussed below, the reductions in indoor use are due partially to a reduction in the number of people living in these homes in addition to changes in water use caused by conservation practices.

Outdoor use is properly examined on an annual basis using billing data as well as logged end use data. Climate variability must also be considered. However, over the logging periods (which were intentionally scheduled at the same time of year in 1996 and 2005) outdoor use declined by more than 40%. A more detailed and rigorous analysis of the changes in outdoor use is presented later in this document.

Table 1: Daily per household water use, 1996 and 2005

		1996 (gpd)	**2005** (gpd)	**% Change**	**Avg. Change in Use (paired data ± 95% CI)**	**Statistically Significant?**
Indoor	Average	173.1	154.1	-11.0%	-19.0 ±15.1	Yes
	Std. Deviation	88.7	75.5			
Outdoor	Average	317.2	188.4	-40.6%	-124.4 ±54.0	Yes
	Std. Deviation	365.4	231.0			
Total	Average	491.0	344.0	-29.9%	-142.7 ±59.8	Yes
	Std. Deviation	388.9	261.2			

Indoor Use

As shown in Table 1 above, indoor use declined by 11% between 1996 and 2005. Figure 4 shows the frequency distributions (histograms) of average daily use in 1996 and 2005. The decline in indoor use is evident in the higher frequency customers in smaller use bins in 2005. Summary statistics are also presented in Figure 4.

Where did the changes in indoor use occur? Table 2 shows significant declines in the average daily per household consumption for all of the major household water uses. The average change in use is shown for the paired households along with the 95% confidence interval. Statistically significant *reductions* in usage were measured in toilet flushing (-21%), clothes washing (-20%), faucet use (-13%), shower use (-15%), and automatic dishwashers (-28%). Leakage, however, showed a statistically significant *increase* from 1996 to 2005 of 52%. Changes in bath use and other/miscellaenous use were not statistically significant.

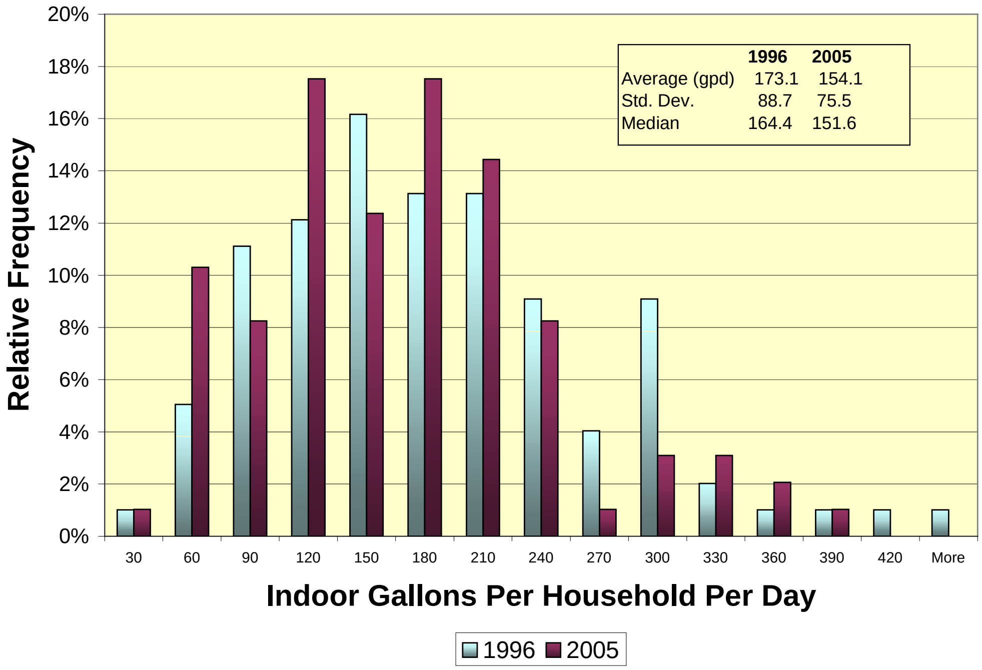


Figure 4: Frequency distribution of indoor gallons per household per day

Table 2: Daily per household indoor use by end-use, 1996 and 2005

Fixture	**Statistic**	**1996** (gpd)	**2005** (gpd)	**% Change**	**Avg. Change in Use** (gpd) (paired data ± 95% CI)	**Statistically Significant?**
Toilets	Average	48.8	38.6	-20.82%	-10.3 ±4.6	Yes
	Std. Deviation	23.6	22.4			
Clothes washers	Average	39.3	31.5	-19.96%	-7.5 ±4.3	Yes
	Std. Deviation	24.6	19.1			
Faucets	Average	24.6	21.5	-12.78%	-3.3 ±2.3	Yes
	Std. Deviation	12.6	12.3			
Showers	Average	34.0	28.9	-15.07%	-5.6 ±4.1	Yes
	Std. Deviation	23.0	23.3			
Baths	Average	3.9	2.9	-26.15%	-1.0 ±1.1	No
	Std. Deviation	5.3	4.5			
Dishwashers	Average	2.8	2.0	-28.27%	-0.9 ±0.4	Yes
	Std. Deviation	2.4	1.8			
Leaks	Average	16.1	24.5	52.05%	9.0 ±8.6	Yes
	Std. Deviation	38.4	40.7			
Other/Misc[4]	Average	3.4	5.7	65.98%	1.3 ±4.1	No
	Std. Deviation	3.8	10.6			

[4] Includes evaporative cooling, humidifiers, water treatment/softeners, and unknown uses.

Toilets

In 1996 the average flush volume per household in the Denver REUWS sample was 3.96 gallons per flush. In 2005 the average flush volume per household was reduced by 20% to 3.14 gallons per flush. A z-test performed on the two samples showed that the difference is statistically significant. This suggests an increase in low flush devices in these homes.

Figure 5 shows the frequency distributions of the average flush volume per household in 1996 and in 2005. Here the change in flush volumes can be easily seen as the 2005 distribution is clearly shifted toward the y-axis indicating a higher frequency of lower flush volumes.

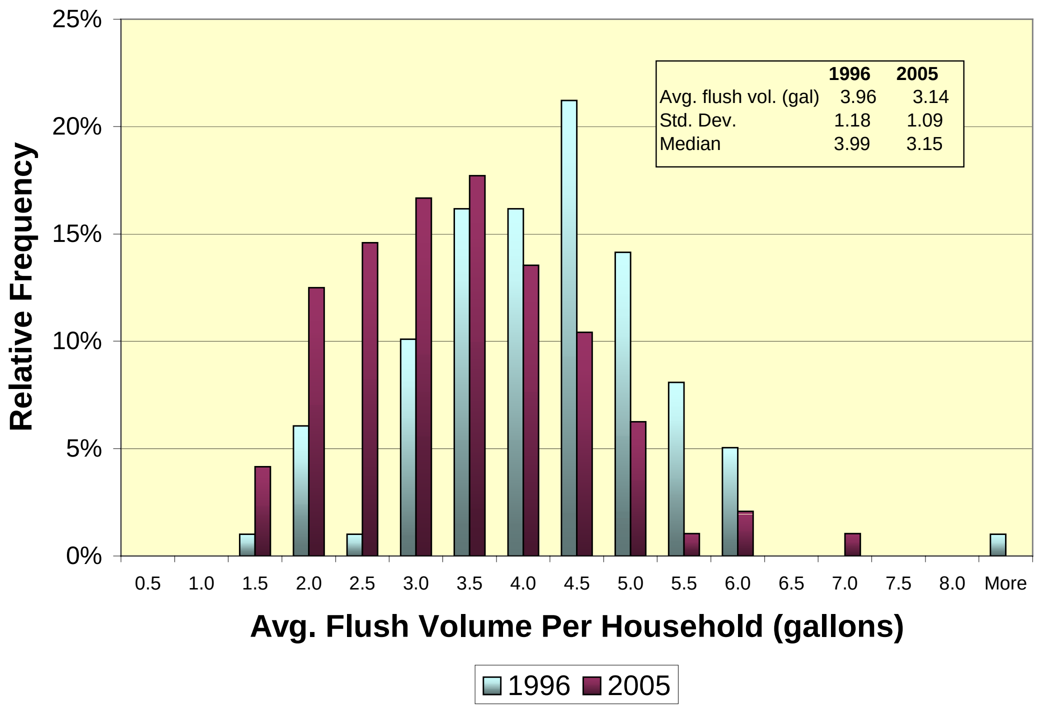


Figure 5: Frequency distribution of toilet flush volume per household, 1996 and 2005

In 1996, only 8.1% of the study homes had an average flush volume of 2.5 gpf or less and only 7.1% had an average flush volume of 2 gpf or less. In 2005, presumably due to the retrofit of ULF toilets over the 9 year gap, 31.3% of the study homes had an average flush volume of 2.5 gpf or less and 19.8% had an average flush volume of 2.05 gpf or less. These results show the impact of the 1992 Energy Policy Act requiring 1.6 gpf toilets and Denver Water's efforts to accelerate installation rates of these fixtures.

Even though the penetration rates of ULF toilets has increased, significant water savings from toilets remain un-captured. The median household flush volume in 2005 was 3.15 gpf. Many old 3.5 gpf and higher flush volume toilets remain in active use. As these inefficient fixtures are upgraded to high efficiency models, additional toilet volume reductions will be achieved.

Using the data collected in this study it was possible to compare the number of homes equipped exclusively with ULF toilets, homes with a mixture of ULF and non-ULF toilets, and homes that do no have any ULF toilets. For the purposes of this analysis any toilet flush of 2 gallons or less was considered a ULF fixture. Homes with an average flush volume of 2.05 gpf or less were considered ULF homes. In 1996, 6.1% of the study homes used ULF toilets exclusively. In 2005 nearly 20% of the study homes used ULF toilets exclusively. The number of homes with a mixture of toilet fixtures changed dramatically from 10.1% in 1996 to 38.5% in 2005. Homes that did not have any ULF flushes decreased by 50% from 1996 to 2005, but still comprise nearly 42% of all homes. These results are presented in Table 3.

Table 3: Toilet fixtures, 1996 and 2005

Toilets in Home	1996	2005
ULF	6.1%	19.8%
Mixed	10.1%	38.5%
Non-ULF	82.8%	41.7%

Flushing Frequency

Results from this study show that the measured 21% reduction in toilet water use is due primarily to technological and hardware changes and *not* to changes in behavior, such as reduced toilet flushing frequency. Flushing frequency (the average number of flushes per household per day) remained essentially unchanged between 1996 and 2005. In 1996 the study homes flushed an average of 12.2 times per day and in 2005 they flushed 12.6 times per day. The difference in flushing frequency was *not* statistically significant. Furthermore, improvements in the flow trace analysis technique allowed for consecutive toilet flushes to be disaggregated in 2005 which may have been lumped into a single event in 1996, which further explains the small difference in observed in flushing frequency.

A comparison of some of the key findings regarding toilet flushing is presented in Table 4. These results indicate that reductions in toilet usage are the result of technological rather than behavioral changes and that substantial technical water savings remain to be captured from additional toilet retrofits.

Table 4: Toilet flush volume, per household use, and utilization rates

Year	Toilet flush volume (gal. per flush)		Daily household toilet use (gallons per day)		Toilet flushes per household per day	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1996	3.96	1.18	48.8	23.6	12.20	4.71
2005	3.14	1.09	38.6	22.4	12.59	5.21

Clothes Washers

Average daily per household clothes washer use declined by nearly 20% from 1996 to 2005 from 39.3 to 31.5 gpd as shown in Table 2. A detailed examination of clothes washer usage indicates that this reduction was accomplished by an 8% decrease in average gallons per load of the clothes washing machines in the study group and a 31% reduction in frequency of clothes washer usage. Both of these changes are statistically significant.

Figure 6 shows the frequency distribution of the average volume per load in 1996 and 2005. In 1996, none of the study homes had a clothes washer that used less than 25 gallons per load on average and only 3.1% had washing machines that used 30 gallons per load or less on average. By 2005, 5.3% of the study homes had a machine that used 25 gallons per load or less and 19% had a machine that used 30 gallons per load or less.

There appears to be significant untapped conservation potential in clothes washer use in Denver. More than 44% of the study homes have a washer that uses more than 40 gallons per load on average and more than 10% of the homes have a washer that uses more than 50 gallons per load. A wide variety of clothes washers that use 30 gallons per load or less are now available and are competitively priced with standard machines. These new machines typically have equal or larger capacity to the standard inefficient models.

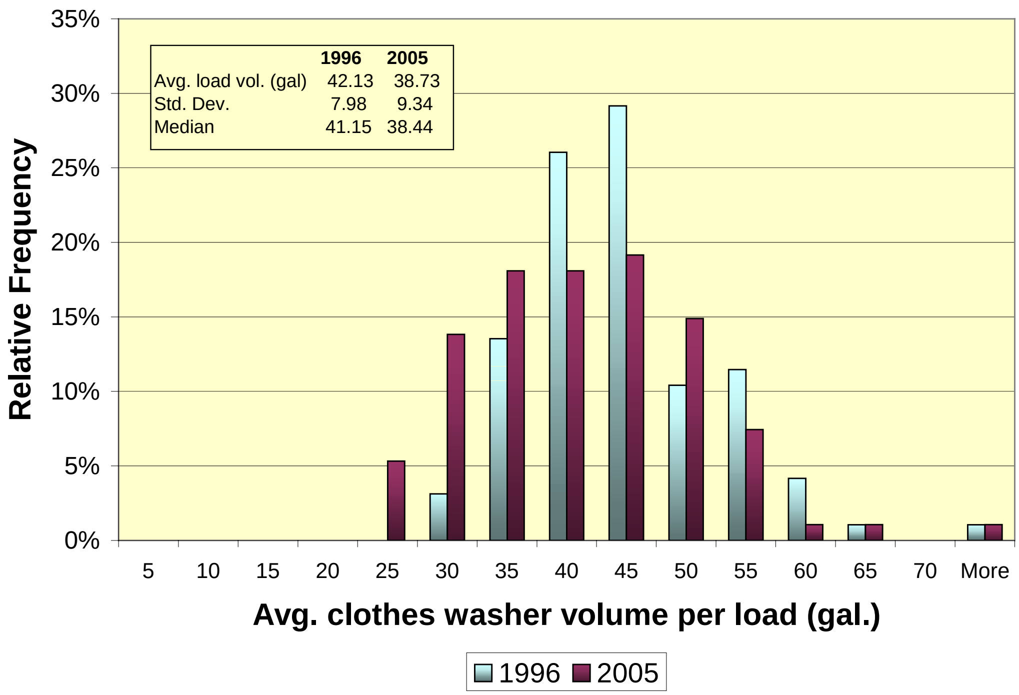


Figure 6: Frequency distribution of clothes washer volume per load, 1996 and 2005

The measured 31% reduction in frequency of clothes washer usage from an average of 0.96 to 0.66 loads per household per day is an interesting result. Summary statistics on clothes washer usage are shown in Table 5. It is unknown exactly why this change occurred, but it could be due to several factors such as: (a) behavior changes - conservation awareness encouraging customers to run fuller (and hence fewer) loads; (b) larger capacity washing machines requiring fewer loads; (c) an increase in off-site laundry (i.e. dry cleaning); (d) change in demographics – fewer people per household; (e) some or all of these or something else.

Table 5: Clothes washer volume per load and utilization rates

Year	Clothes washer volume per load (gallons)		Clothes washer loads per household per day	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
1996	42.13	7.98	0.96	0.54
2005	38.73	9.34	0.66	0.49

Showers

Daily per household shower use fell by a statistically significant 15% from 34.0 to 28.9 gallons per household per day from 1996 to 2005. Interestingly this was the only relevant showering statistic that showed a statistically significant change. Showering results are shown in Table 6 and

Table 7.

The average volume of showers was 17.8 gallons in 1996 and 16.8 gallons in 2005, but the difference was not statistically significant. The average shower duration was virtually identical at 7.9 minutes in 1996 and 8.0 minutes per shower in 2005. The typical flow rate for showers reduced from 2.36 gpm to 2.21 gpm between 1996 and 2005, but again the difference is not statistically significant.

Table 6: Household shower use, shower volume, and flow rate, 1996 and 2005

Year	**Daily per household shower use** (gpd)		**Shower volume*** (gallons)		**Shower flow rate*** (gpm)	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
1996	34.0	23.0	17.8	5.6	2.36	0.64
2005	28.9	20.7	16.8	6.0	2.21	0.63

*Difference between 1996 and 2005 is NOT significant at 95% confidence level

The number of showers per household per day decreased by 12% from 1.87 to 1.64 showers per day. Although this difference appears reasonably large it was not statistically significant .

The net result of the analysis of shower usage is a bit of a muddle. Although daily household use declined, it appears this reduction is possible the result of random variations in showering habits rather than a measurable change in technical efficiency or behavior. The combination of modest reductions in shower flow rate and frequency appear to have resulted in the decline in daily household use. However it is not clear that these reductions are significant or permanent given the results of the analysis.

Table 7: Shower duration and shower uses per day, 1996 and 2005

Year	Shower duration* (minutes)		Shower uses per household per day*	
	Mean	Std. Dev.	Mean	Std. Dev.
1996	7.9	2.5	1.87	1.05
2005	8.0	2.8	1.64	0.99

*Difference between 1996 and 2005 is NOT significant at 95% confidence level

Faucets

Faucet use declined from 24.6 gpd to 21.5 from 1996 to 2005. This 12.8% reduction is statistically significant. This reduction was accomplished primarily through a small but statistically significant reduction in faucet flow rate. Average per household faucet flow rates were 1.28 gpm in 1996 and were reduced by 8% to 1.18 gpm in 2005. The amount of time faucets were used each day declined from an average of 21.35 minutes in 1996 to 20.63 minutes in 2005, but this difference was not found to be statistically significant. These results are presented in Table 8.

Table 8: Faucet use, duration, and flow rate, 1996 and 2005

Year	**Daily per household faucet use** (gpd)		**Faucet use daily duration*** (minutes)		**Faucet flow rate** (gpm)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1996	24.6	12.6	21.35	10.71	1.28	0.24
2005	21.5	12.3	20.63	11.61	1.18	0.19

*Difference between 1996 and 2005 is NOT significant at 95% confidence level

Dishwashers

Daily per household dishwasher use declined by more than 28% as shown in Table 2. This reduction was accomplished almost exclusively through efficiency improvements in dishwashers. In 1996 the average dishwasher in Denver used 10.38 gallons per load (gpl). In 2005 this had been reduced by nearly 24% to 7.9 gallons per load, a statistically significant result. The number of dishwasher loads per household per day remained virtually unchanged from 0.34 loads per day in 1996 to 0.32 loads per day in 2005. This small difference is not statistically significant.

Dishwashers have a shorter useful service life than clothes washers and it appears that the study group replaced dishwashers (without any financial incentive from Denver Water) at a higher rate than they replaced clothes washers. More than 77% of the dishwashers in the study homes used 9 gallons per load or less on average. Nearly 23% of the dishwashers used less than 6 gallons per load.

Table 9: Dishwasher volume per load and loads per day, 1996 and 2005

Year	Dishwasher volume per load (gallons)		Dishwasher loads per household per day*	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
1996	10.38	3.19	0.34	0.20
2005	7.90	2.59	0.32	0.18

*Difference between 1996 and 2005 is NOT significant at 95% confidence level

Leaks

Household leaks are highly variable and unpredictable. One house may have a large leak for a number of days, and then the leak disappears after repairs. The houses that are leaking at any time may be different as leaks develop and stop. In this sample leakage increased by 52% from 1996 to 2005. This alone was enough to negate many of the savings gains earned through toilet and clothes washer retrofits. If the houses had been leak free their daily use would have been only 130 gpd, or 47 kgal/year. Unfortunately the flow trace analysis technique used in this study cannot isolate the source of leaks. The leakage category is a "catch all" for continuous low flow (<0.4 gpm) water uses and for regularly occurring flapper leaks which are the only type of leak that can be attributed to a specific fixture. It is generally not possible to determine if a leak is occurring indoors or outdoors. In this analysis all leaks have been included in the indoor use category.

The disaggregation of leakage is less precise than some of the other fixture identification such as toilets, clothes washers, dishwashers, and irrigation. There may be some interaction between leaks and faucets and other potentially low flow events such as evaporative cooling and humification. Regardless of the classification, the flows identified as leaks do represent real water uses and as such must be considered an important finding of this research

Figure 7 compares the distribution of average daily leakage in 1996 and 2005. Average daily per household leakage was 16.1 gpd in 1996 and 24.5 gpd in 2005. The median daily leakage tells the story. In 1999, 50% of the study homes leaked 3.1 gpd or less. In 2005, 50% of the study homes leaked 8.6 gpd or less. The number of homes in the 30+ gpd leakage range increased from 13% in 1996 to 24% in 2005.

Determining the cause of the leakage in 2005 is a speculative exercise in most cases. The most likely cause is the aging toilet stock in the study group. Although a significant number of toilets were changed out over the past 10 years, many older toilets (and likely toilet flappers) remain. Older toilets are not the only culprits as persistent flapper leaks were occasionally observed in association with ULF toilets as well. Other causes of household leakage include faulty irrigation valves and faucets that cannot be fully shut off. Leaks from pipes and plumbing occur, but are usually quickly discovered and repaired since they often cause visible damage.

After initial review of the leak information reported, Denver Water Conservation staff has determined that the best alternative for determining the causes of the leaks will be to offer water

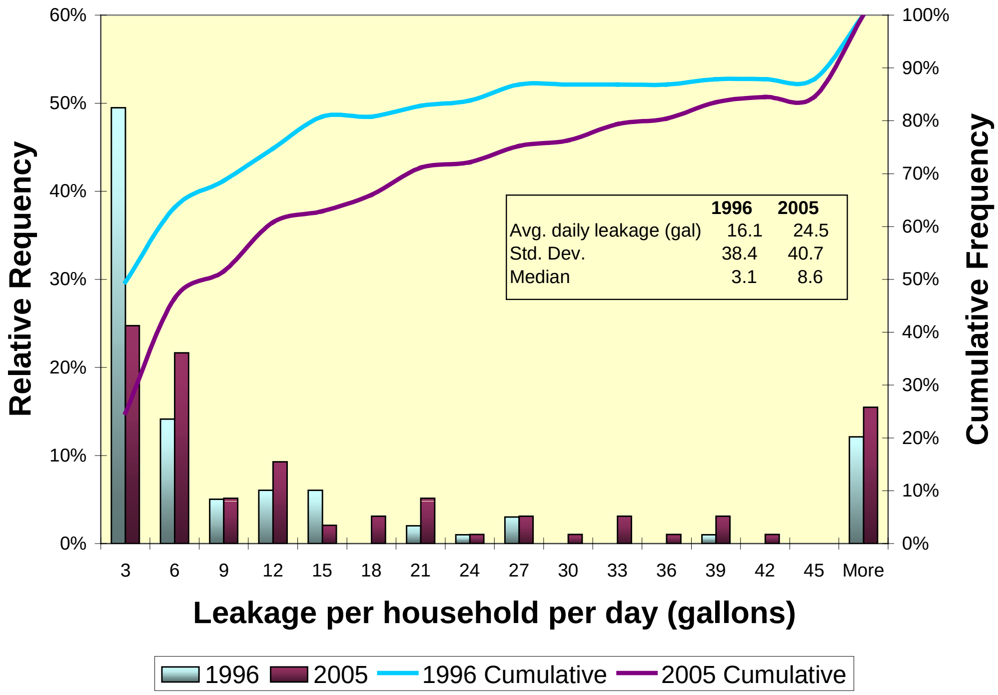


Figure 7: Frequency distribution of leakage, 1996 and 2005

audits to the homes where significant leakage occurred as well as re-examining the flow traces to identify the source where possible.

Other/Miscellaneous

Table 10 compares miscellaneous end uses in 1996 and 2005 and the measured penetration of these different uses. There are no particularly startling changes to report here. Ten years of experience with flow trace analysis has enabled us to better identify evaporative cooling and water treatment in 2005. The penetration rate of evaporative cooling is essentially unchanged. More water treatment was identified in 2005. Likely some of this use was classified as unknown in 1996. The unknown category is used when the analyst is unable to positively identify an end use. Unknown uses could be indoors or outdoors, but are typically included in the indoor use total.

Table 10: Miscellaneous end uses, 1996 and 2005

End Use	**1996 Average daily per household use** (gpd)	**2005 Average daily per household use** (gpd)	**1996 - % of study homes with end use**	**2005 - % of study homes with end use**
Evaporative Cooler	0.8	3.1	9.1%	9.3%
Humidifier	0.05	0.9	2.0%	2.0%
Treatment	0.05	1.2	3.0%	6.2%
Unknown	2.5	1.3	83.8%	81.4%

Per Capita Use and Household Size

Completed survey data including the number of residents in each home were available for 79 of the data logged homes in the 2005 study. Using the reported number of residents, the number of residents and per capita daily indoor use were calculated for the same study homes in 1996 and 2005. Table 11 presents the results.

The average number of residents (adults, teens, and children) reduced from 2.77 in 1996 to 2.51 in 2005. Although not statistically significant, this change does represent a 9.4% reduction in the number of people living in the study homes. Daily per capita indoor water use reduced slightly (and without statistical significance) from 67.66 gcd in 1996 to 65.19 in 2005, a 3.7% reduction.

Table 11: Number of residents and daily per capita indoor use, 1996 and 2005

Year	**Number of residents per household***		**Daily per capita indoor water use*** (gcd)	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
1996 (n=78)	2.77	1.32	67.66	31.52
2005 (n=79)	2.51	1.29	65.19	31.40

*Difference between 1996 and 2005 is NOT significant

These results suggest that the 11% reduction in indoor household use described in Table 1 may be at least partially due to a change in the demographics of the study sample. Clearly there have been significant and substantial reductions in toilet, clothes washer, and other indoor uses, however there has also been a cross cutting increase in leakage and other miscellaneous household uses such as evaporative cooling and humidification. The net result is only a small decrease in per capita use.

In order to correct for errors caused by changes in the number of residents living in the homes regression models were prepared for the 67 homes for which the number of residents was known for both periods. The data were first transformed in log values because the log of the water use fit a normal distribution better than did the raw water use data. This also has the effect of eliminating the effect of the number or residents per home by making it one of the variables. Regression models were created for the daily water use verses the number of residents and the size of the homes, which from previous studies were found to be the most useful as explanatory variables for this purpose. The resulting equations were:

HH = 17.78 * SF^.215 * RES^.5725 for the 1996 data; and

HH = 13.38 * SF^.2414 * Res^.577 for the 2005 data

Plots of these equations for an average size house, of 2100 square feet, are shown in Figure 8.

The individual data points for the equation lines are shown in Table 12. This allows the change in water use to be calculated for each size household. On average, these data show a 7.4% reduction in indoor water use between 1996 and 2005. This tends to be fairly consistent homes with different numbers of residents. An average reduction of 7.4% in indoor water use for the homes is a more reliable one than one based on a simple comparison of mean since it corrects for both household size and population.

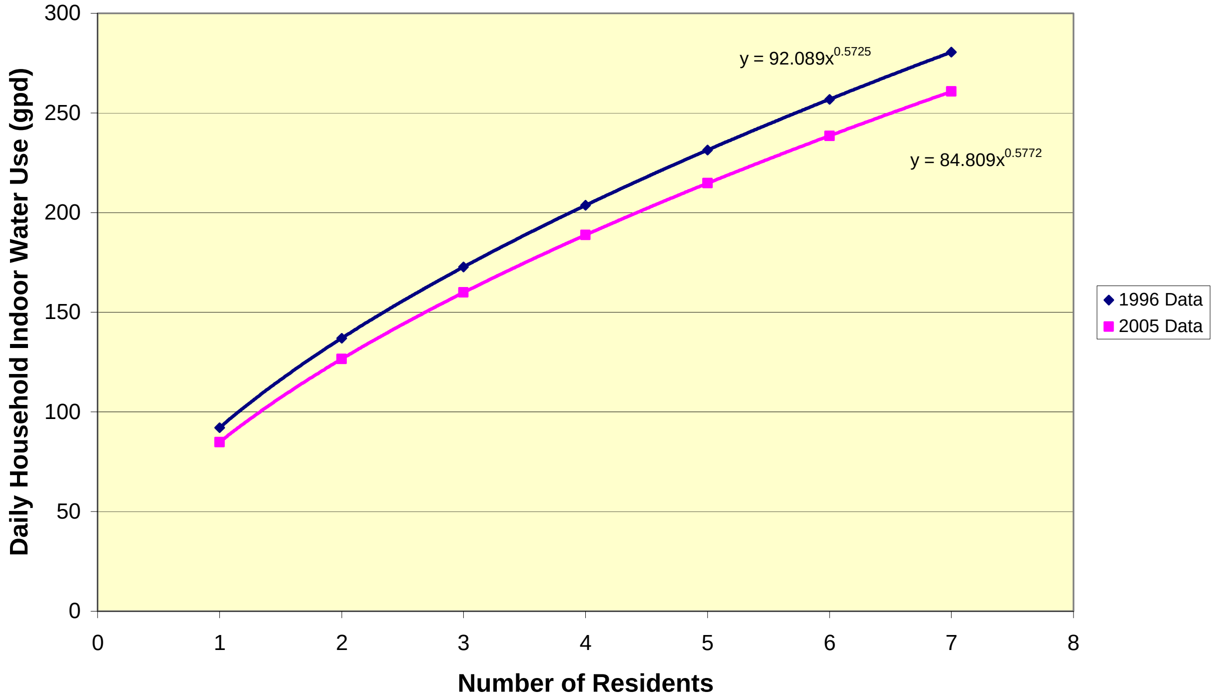


Figure 8: Household indoor water use vs. number of residents for 2100 sf home

Table 12: Household indoor use vs. residents for 2100 sf home

Res No.	SF	HH2005	HH1996	Reduction	% Reduction
1	2100	84.81	92.09	7.28	7.9%
2	2100	126.53	136.95	10.42	7.6%
3	2100	159.89	172.73	12.83	7.4%
4	2100	188.77	203.65	14.88	7.3%
5	2100	214.72	231.40	16.68	7.2%
6	2100	238.55	256.86	18.31	7.1%
7	2100	260.75	280.56	19.81	7.1%
				Average	**7.4%**

The per capita use analysis further reinforces the finding that substantial indoor conservation potential remains among Denver Water customers. Recent retrofit studies conducted for the US EPA by Aquacraft indicate that per capita use can be reduced to 40 gcd or lower through full toilet, clothes washer and faucet aerator retrofits (2004, DeOreo, et. al.). High efficiency toilets (HETs) that use 1.0 gallon per flush (or less) and super high efficiency washing machines that are now available should reduce per capita consumption even more. Progress has been made in Denver, but there is still a lot of room for water savings without requiring behavior changes or sacrificing quality of life in any way.

Outdoor Use by Q100

While changes in the indoor use for these customers are subtle, the changes in outdoor use are more dramatic. Annual outdoor water use was estimated by subtracting the measured indoor water use (from the logged data) from the metered water use from the billing database. The results showed a major reduction in water used for irrigation between the two years. However, as will be seen, a large portion of this reduction can be explained by the difference in the weather between the two years.

In 1994, the year for which the billing data were used for the 1996 study, the customers in the Q100 used an average of 102 ± 17 kgal of water outdoors. In 2004 this dropped to 48 ± 3.7 kgal. This represents a reduction of 54 kgal, which is 53% of the 1994 outdoor use. This result dwarfs the change in indoor use estimated at 7 kgal per year above. These results are shown in Figure 9. Upon closer examination, however, it becomes clear that not all of this reduction was due to conservation efforts.

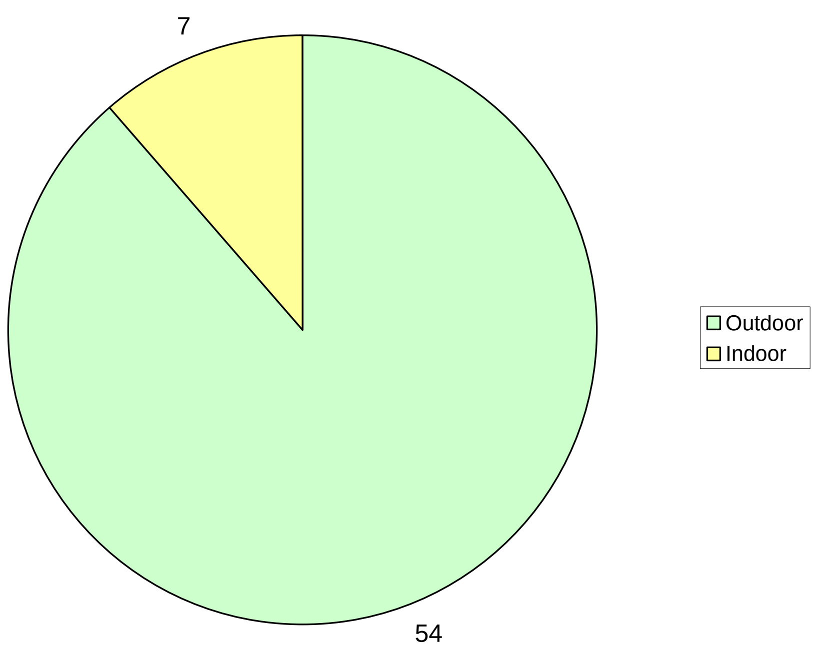


Figure 9: Comparison in indoor and outdoor water use changes between 1994 and 2004 (kgal)

It can be seen in Figure 10 that the net ET in 2004 was much smaller than that in 1994. These data were obtained using the NOAA weather station at Stapleton and the Blaney-Criddle procedure, which requires only temperature and rainfall data. This allows ET to be calculated back to 1949, when the weather station went into operation. The data show that 1994 actually had the highest net ET for the period, and 2004 had one of the lowest. It would be misleading to compare the two years and assume that the difference could be attributed to any specific water conservation efforts, when in fact all or a portion of the reduction could be due to the fact that there was less need for irrigation water in 2004.

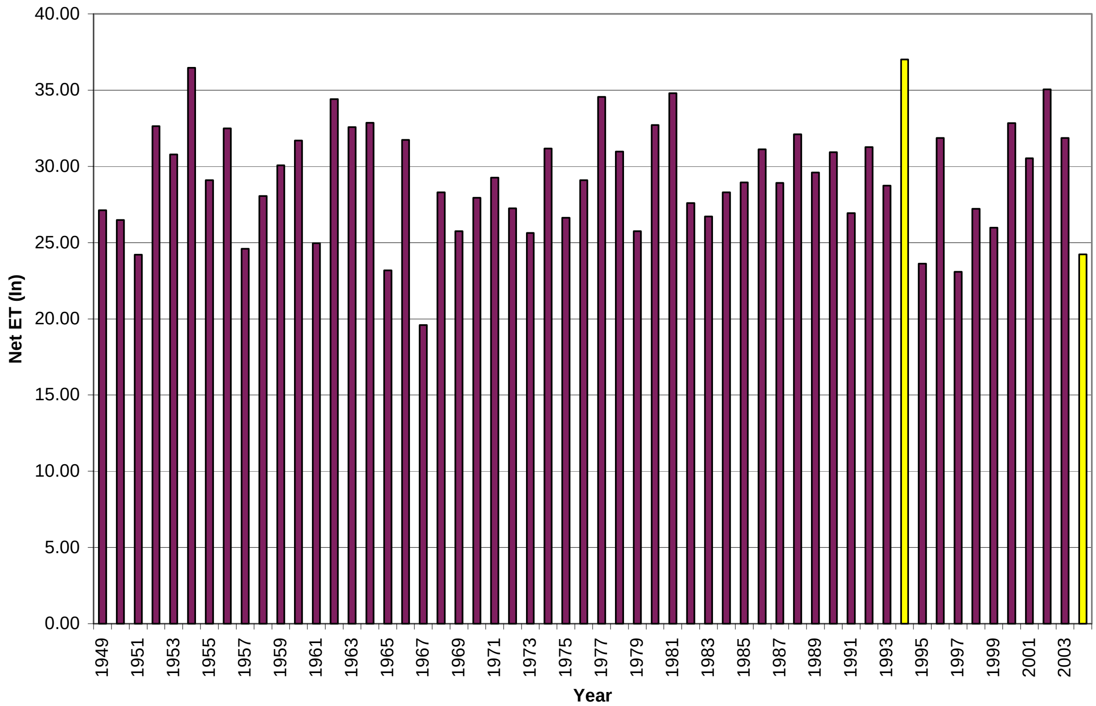


Figure 10: Annual Net ET 1949-2004, Denver Stapleton Weather Station

In Figure 11 the irrigation application rates for the homes is plotted along with the net ET for the years 1994, and 2000 through 2004. This figure is similar to Figure 3, which showed the outdoor water use for the Q1000 and net ET. Like Figure 3, the downward trend in irrigation application parallels the downward trend in net ET. The exception to this is 2002. In 2002, even though the net ET rose significantly, the irrigation applications dropped slightly. In 2003, the second year of the drought, irrigation applications made a larger drop. It appears that the drop in application rates was larger in 2003 and 2004 than the corresponding drop in net ET. The data shown in Figure 12 confirms this. In the three non-drought years the irrigation applications averaged 86% of the net ET. In 2002, the first year of the drought this average dropped to 70% of net ET. The applications in 2003 were the smallest in terms of net ET, dropping to 55%. In 2004 as the effects of the drought diminished the application rose slightly to 59% of net ET. When the data for 2005 become available it would be interesting to see whether this rebound in use has continued. This graph also reinforces the point that it took a year to reach the maximum impacts from the mandatory restrictions, and that during the first year of the drought they had only a modest effect.

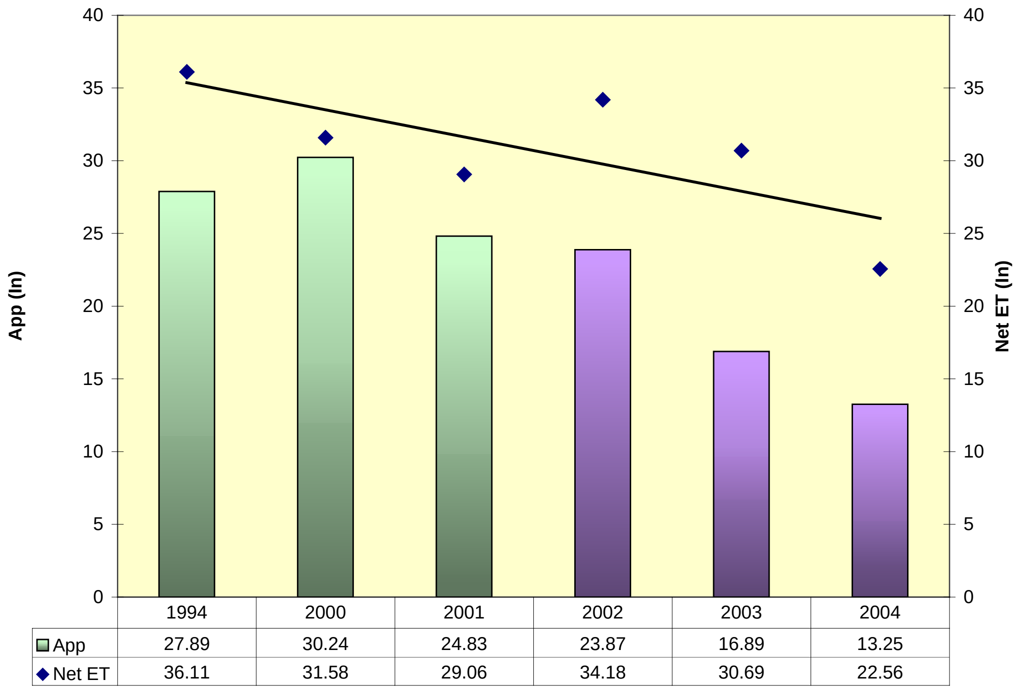


Figure 11: Irrigation applications and net ET

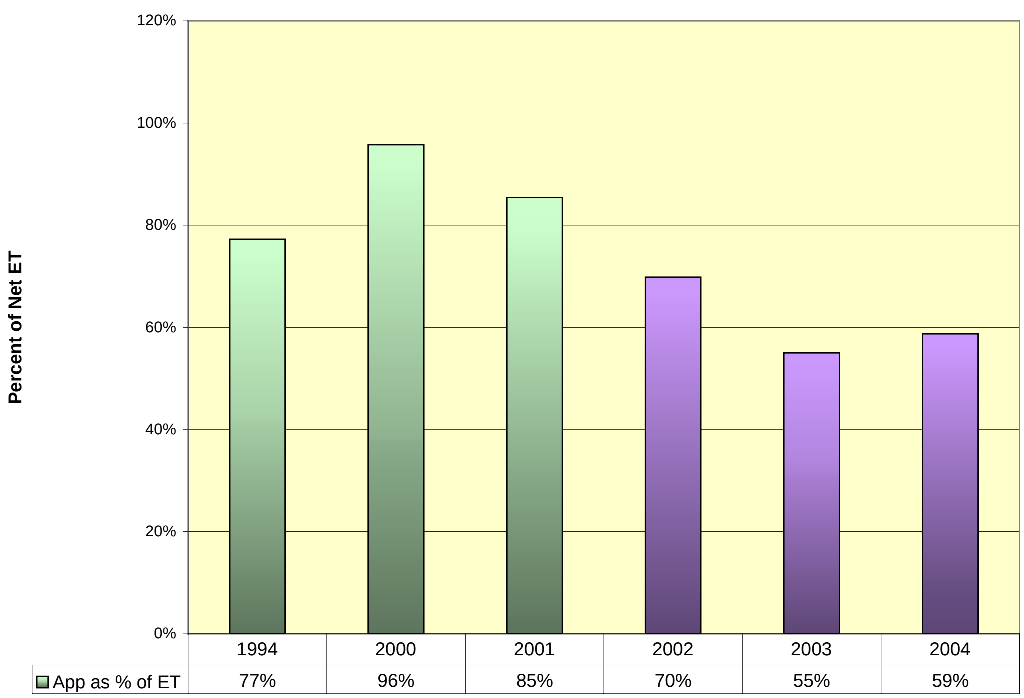


Figure 12: Irrigation applications as percent of net ET

Irrigation Patterns During the Logging Period

Of the 93 logged homes during the summer of 2005, 83 (89%) used water for irrigation purposes during the two-week logging period, and10 of the homes (11%) did no irrigation even during the hottest part of the summer. The maximum irrigation use during the logging period was 22,484 gallons and the average (of the homes that irrigated) was 5,265 gallons for the two-week period or 382 gallons per day. Details about the water use of each home and the irrigation system can be found in the tables in the appendix.

A total of 2.63 inches of rain fell during the logging period with most the rain occurring from June 1-12. In general, the July logging period was hot and dry. Table 13 shows the ET_o, rainfall, and net ET_o for the entire data collection period. The ET_o and rainfall shown in Table 13 came from Denver Water's 56th Ave. weather station. This was the only local weather station that had complete data for the logging period. A comparison of this site with other weather stations in the area indicated that ET at 56th Ave. tends to be slightly higher than at other sites. Data from this site indicated that the average daily ET_o was 0.25 inches per day, and the total ET_o during the logging period was 15.45", which is equivalent to 9.63 gallons per square foot[5] of irrigated area. The 2.63 inches of rainfall during the period would reduce this to a net requirement of 13.82" or 8.6 gpsf. This is the amount of water that a reference crop (cool season turf) would require during the period for optimum growth.

Table 13: ET during 2005 logging period

Date	ETo	Rainfall	Net ET
1-Jun	0.25	0	0.25
2-Jun	0.15	0.38	0
3-Jun	0.13	0.35	0
4-Jun	0.08	0.31	0
5-Jun	0.25	0	0.25
6-Jun	0.27	0	0.27
7-Jun	0.25	0	0.25
8-Jun	0.26	0.02	0.244
9-Jun	0.17	0.59	0
10-Jun	0.06	0.37	0
11-Jun	0.22	0.16	0.092
12-Jun	0.11	0.09	0.038
13-Jun	0.28	0	0.28
14-Jun	0.24	0	0.24
15-Jun	0.20	0	0.2
16-Jun	0.25	0	0.25
17-Jun	0.32	0	0.32
18-Jun	0.27	0	0.27
19-Jun	0.28	0	0.28
20-Jun	0.24	0.04	0.208
21-Jun	0.28	0	0.28
22-Jun	0.27	0	0.27
23-Jun	0.24	0.03	0.216
24-Jun	0.22	0.03	0.196
25-Jun	0.23	0.01	0.222
26-Jun	0.27	0	0.27
27-Jun	0.30	0	0.3
28-Jun	0.25	0	0.25
29-Jun	0.28	0	0.28
30-Jun	0.28	0	0.28
1-Jul	0.3	0	0.3
2-Jul	0.29	0	0.29

[5] One inch of water = 0.623 gallons per square foot.

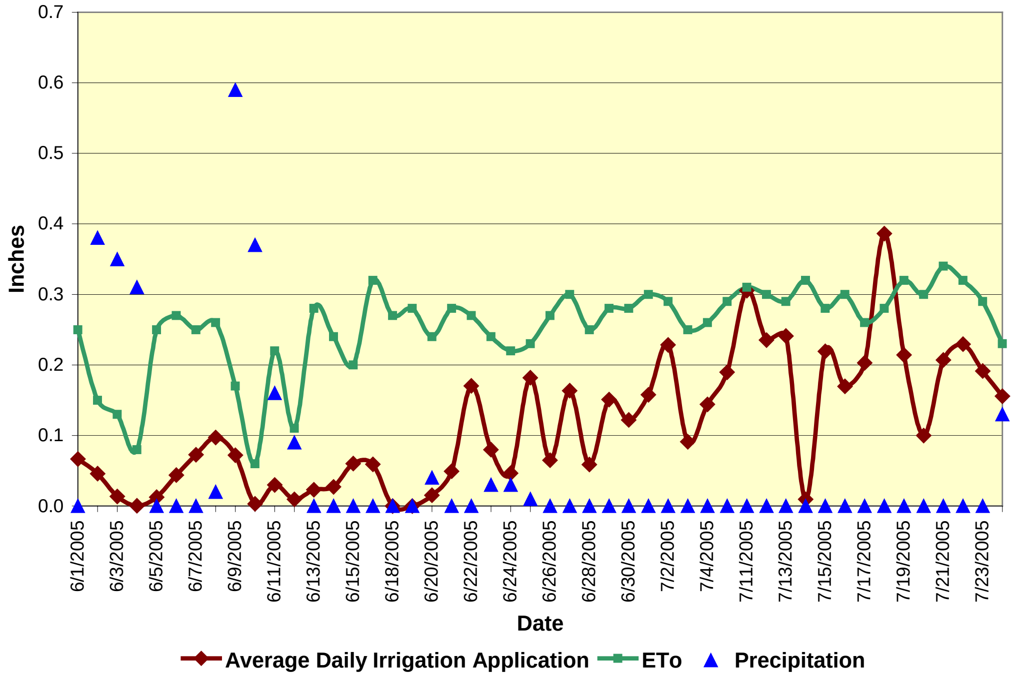
Date	ETo	Rainfall	Net ET
3-Jul	0.25	0	0.25
4-Jul	0.26	0	0.26
5-Jul	0.21	0	0.21
6-Jul	0.27	0	0.27
7-Jul	0.33	0	0.33
8-Jul	0.3	0	0.3
9-Jul	0.25	0	0.25
10-Jul	0.29	0	0.29
11-Jul	0.31	0	0.31
12-Jul	0.3	0	0.3
13-Jul	0.29	0	0.29
14-Jul	0.32	0	0.32
15-Jul	0.28	0	0.28
16-Jul	0.3	0	0.3
17-Jul	0.26	0	0.26
18-Jul	0.28	0	0.28
19-Jul	0.32	0	0.32
20-Jul	0.3	0	0.3
21-Jul	0.34	0	0.34
22-Jul	0.32	0	0.32
23-Jul	0.29	0	0.29
24-Jul	0.23	0.13	0.126
25-Jul	0.19	0.12	0.094
26-Jul	0.1	0	0.1
27-Jul	0.25	0	0.25
28-Jul	0.28	0	0.28
29-Jul	0.31	0	0.31
30-Jul	0.29	0	0.29
31-Jul	0.24	0	0.24
Average	0.25	0.04	0.23
Total	15.45	2.63	13.82

Comparison of Actual Irrigation to Evapotranspiration

The average daily application rate for the homes was tracked along with ET_o and precipitation to evaluate how much of the reference requirement the customers were applying, and how they responded to changes in prevailing weather conditions. This information is shown in Figure 13. The data show that the average application rate only exceeded ET_o on one day (July 20) during the data collection period. In general, water use tracked the changes in ET quite well, except it was consistently lower--particularly during the early days in June when there was significant precipitation. The figure shows that the customers responded to the rainfall during the beginning of June and end of July by reducing their irrigation. The lowest irrigation use of the logged days occurred during the 11 days following the rain of June 9th. Application rates increased for much of the July, and as the number of rainless days increased the actual application line approached the reference line more closely. On July 22 – 24 at the end of the logging period when more rainfall occurred, residents again promptly responded by reducing irrigation application. The response of this group to changes in ET and rainfall is noteworthy.

This figure also shows that the customers generally irrigated at a fraction of ET levels. Only on a single day did the application rates of the group exceed the daily ET, and this was after a long rainless period. More information on the percentage applications is given in the following tables, but this figure shows that the general pattern is for the customers to water at significantly below ET levels.[6]

[6] This has implications for water saving potential of new technologies such as ET irrigation controllers that are designed to water at ET levels.



[DA1]

Figure 13: Average daily irrigation application and ETo during logging period

Figure 14 again shows the deficit irrigation patterns of this group by comparing the cumulative average irrigation application to the cumulative ET_o during the logging period. Here it can be clearly seen that residents in Denver were applying substantially less water than was theoretically required. By the end of the logging period the study sites had applied less than 43% of the net ET requirement over that same period. The active response to changes in the weather and significantly lower than ET_o application rates suggest that these Denver residents were being quite careful about outdoor watering in the wake of the drought and the watering restrictions imposed by Denver Water. According to the REUWS study, in 1996 the Denver customers applied 85% of ET to their landscapes[7].

[7] See Table 5.15, page 118 of REUWS. (AWWARF, 1999). The REUWS estimates used annual data while this memo uses data for just the June-July period, so caution should be used in comparing them.

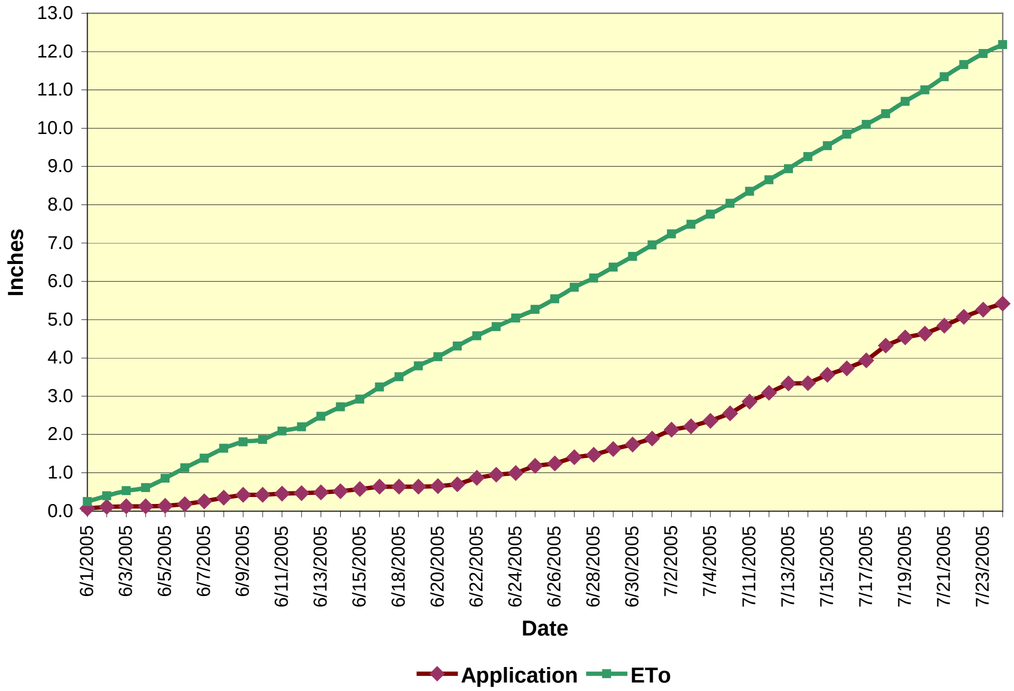


Figure 14: Cumulative irrigation application and ETo over logging period

Landscape Coefficient and Theoretical Irrigation Requirement

The reference irrigation application represents the amount of water required to sustain a total turf landscape. We know that few customers have such a uniform landscape, so the question naturally follows as to what percentage of their actual irrigation requirement the customers are applying. This is determined by calculating a factor called the landscape coefficient for each lot, which is the ratio of the actual requirement for the particular landscape to the reference requirement. The landscape coefficient takes into account all of the factors that go into determining water requirement, including plant types, exposures, densities and irrigation efficiencies. The landscape coefficient and theoretical irrigation requirement were calculated for each home in the sample primarily using survey and landscaped area data obtained in the REUWS surveys, by graduate student research[8] as well as GIS data provided by Denver Water. These data are presented in Table 14 with the summary data presented at the top of the table because of the overall size. On average the landscape coefficient for the group was 1.06, which is slightly over ET levels.[9]

The landscape coefficient is useful because when multiplied by ET_o and the irrigated area, the product is the theoretical irrigation application requirement for the site. This allows for comparisons between sites with different landscapes and with different irrigation application efficiencies. Because audits were not performed as part of this study, much of the data for the calculation of K_L was taken from typical landscape values for the Denver area.

[8] Stadjuhar, Laurel E., *Outdoor Residential Water Use*. Masters Thesis, University of Colorado, 1997

[9] The irrigation requirement equals the plant water requirement divided by the irrigation efficiencies. This results in the landscape coefficient being greater than the reference ET for landscapes that have substantial amounts of turf with zone efficiencies typically around 70%.

Table 14: Landscape Coefficient and Theoretical Irrigation Requirement (sites where irrigation occurred.

Keycode	Irrigated Area (sf)	ET_o logging period (in.)	K_L (landscape coefficient)	Theoretical Application Requirement logging period (gal.)	Actual Application logging period (gal.)	Actual Application as a Percent of Theoretical Requirement (logging period)
Average	7,151	3.35	1.06	15,912	5,205	40.6%
Median	3,930	3.65	1.07	11,239	3,443	30.9%
Std. Deviation	9,945	0.54	0.15	24,972	5,228	38.0%
Min	1,554	2.67	0.73	2,276	40	0.5%
Max	76,666	4.02	1.32	230,869	22,485	165.2%
11005	5,250	2.67	1.19	10,417	190	1.83%
11014	3,750	2.72	1.32	8,415	4,989	59.3%
11015	3,750	3.72	1.19	10,367	7,562	72.9%
11029	2,814	2.72	0.96	4,591	1,117	24.3%
11032	3,798	2.72	1.32	8,523	60	0.7%
11034	3,750	2.72	1.06	6,745	2,692	39.9%
11035	13,360	3.65	0.86	26,257	17,447	66.4%
11037	8,360	3.72	0.86	16,745	6,494	38.8%
11059	5,698	2.67	0.93	8,815	1,841	20.9%
11062	7,019	3.73	1.00	16,241	2,061	12.7%
11063	3,750	4.02	1.03	9,660	10,984	113.7%
11070	3,900	2.72	0.80	5,278	359	6.8%
11076	8,960	3.65	0.73	14,932	1,139	7.6%
11079	3,444	3.72	0.80	6,408	4,618	72.1%
11082	3,570	2.72	1.26	7,614	40	0.5%
11084	9,520	2.67	1.13	17,849	877	4.9%
11085	9,120	2.67	1.26	19,093	5,038	26.4%
11092	2,814	2.72	1.19	5,688	1,651	29.0%
11094	7,738	2.67	1.00	12,816	1,782	13.9%
11098	6,312	2.67	1.06	11,144	4,887	43.9%
11101	2,622	3.65	1.13	6,720	6,240	92.9%
11112	17,760	3.65	1.00	40,212	21,321	53.0%
11116	1,554	2.72	0.86	2,276	1,606	70.6%
11121	3,750	3.65	1.26	10,732	6,322	58.9%
11124	1,872	4.02	0.73	3,436	1,066	31.0%
11135	6,720	3.72	1.19	18,578	6,359	34.2%
11137	15,000	2.67	1.13	28,124	3,312	11.8%
11141	10,800	2.67	0.93	16,707	206	1.2%
11146	3,711	4.02	1.00	9,254	6,883	74.4%
11167	8,256	3.72	0.80	15,280	9,092	59.5%
11175	8,600	3.72	1.13	22,465	3,015	13.4%
11178	2,814	4.02	0.93	6,554	415	6.3%
11183	3,810	3.72	1.03	9,082	5,056	55.7%
11186	3,024	2.72	1.13	5,776	919	15.9%
11187	2,814	3.65	0.80	5,110	6,507	127.3%
11208	2,814	2.72	0.86	4,121	1,317	32.0%
11234	3,600	3.65	1.19	9,765	1,904	19.5%
11236	7,434	3.73	1.19	20,607	2,744	13.3%
11239	3,750	3.72	1.19	10,367	196	1.9%
11243	5,467	2.72	1.19	11,051	1,305	11.8%
11245	5,992	3.65	0.93	12,672	9,429	74.4%
11247	76,666	3.65	1.32	230,869	19,913	8.6%
11251	4,504	4.02	1.19	13,456	4,133	30.7%
11253	3,750	2.72	1.19	7,580	2,457	32.4%
11256	20,520	2.67	0.86	29,501	2,149	7.3%
11258	7,265	2.67	0.93	11,239	126	1.1%
11263	2,340	4.02	1.09	6,413	809	12.6%

Keycode	Irrigated Area (sf)	ET_o logging period (in.)	K_L (landscape coefficient)	Theoretical Application Requirement logging period (gal.)	Actual Application logging period (gal.)	Actual Application as a Percent of Theoretical Requirement (logging period)
11265	6,720	3.72	1.06	16,531	7,205	43.6%
11266	3,000	3.73	1.09	7,629	1,259	16.5%
11268	3,600	4.02	1.09	9,866	12,283	124.5%
11269	6430	2.67	1.06	11,353	582	5.1%
11270	5740	3.65	0.93	12,139	7,409	61.0%
11271	4949	3.73	1.00	11,451	998	8.7%
11281	15,251	3.72	1.00	35,194	22,485	63.9%
11289	9,620	3.72	1.06	23,664	4,865	20.6%
11299	7,003	4.02	1.19	20,921	7,356	35.2%
11300	3,960	4.02	1.19	11,830	6,065	51.3%
11302	2,814	4.02	1.13	7,944	13,121	165.2%
11303	4,140	3.72	1.13	10,815	16,741	154.8%
11309	8,677	2.67	1.19	17,217	2,783	16.2%
11312	3,750	3.72	1.13	9,796	10,731	109.5%
11319	3,786	3.65	0.75	6,445	9,232	143.2%
11326	2,856	3.65	1.13	7,320	2,664	36.4%
11329	11680	3.65	0.93	24,701	12,983	52.6%
11348	11386	2.67	1.26	23,837	278	1.2%
11352	9553	3.72	1.00	22,045	9,667	43.8%
11353	6902	2.67	1.19	13,695	3,230	23.6%
11356	4984	2.67	1.26	10,434	5,417	51.9%
11363	8160	2.72	1.26	17,403	9,775	56.2%
11364	10080	3.72	1.19	27,866	5,930	21.3%
11368	8101	3.72	0.93	17,460	2,603	14.9%
11372	8114	2.67	1.06	14,326	425	3.0%
11382	3600	2.67	1.06	6,356	455	7.2%
11387	6482	4.02	1.09	17,765	18,314	103.1%
11392	6482	2.72	0.86	9,493	2,930	30.9%
11407	5124	3.72	1.13	13,385	4,813	36.0%
11417	5880	4.02	1.00	14,663	9,063	61.8%
11420	5355	3.65	1.03	12,525	4,240	33.9%
11432	8640	3.65	1.03	20,208	3,443	17.0%
11448	2814	3.72	1.00	6,494	6,001	92.4%
11456	3600	3.73	1.32	11,079	864	7.8%
11463	4719	2.67	1.00	7,816	1,339	17.1%
11465	6142	3.72	0.95	13,519	3,850	28.5%

The ET_o was calculated for each site based on the actual logging period. When the project started in early June the weather was unusually cool and wet. The logging period in late June and July was hot and dry for the most part, so there is a fair amount of variability in the ET corresponding to each study site.

Overall the study group used substantially *less* water than theoretically required. On average the study homes that irrigated applied 40.6 percent of the theoretical requirement. Well over half the study homes used 30% or less of the theoretical requirement. About 10% of the homes had no irrigation at all during the logging period. *Only 8 of the study homes used more than 100% of the theoretical requirement.* A histogram of the actual application as a percentage of the theoretical requirement is shown in Figure 15. The overall implication of this result is that a substantial majority of the single-family homes in Denver are using significantly less water than their landscapes might require for full health and growth. In reality, many landscapes look acceptable even when they receive only 50% of the theoretical requirement. A review of the historical water billing data for this sample shows a marked decrease in outdoor water use from 2000 through 2004 (as discussed above). During the logging period there are a small number of homes (less than 10 percent) that use substantially more water for irrigation than appears to be required. Targeting outdoor efficiency efforts at this group of customers makes the most sense.

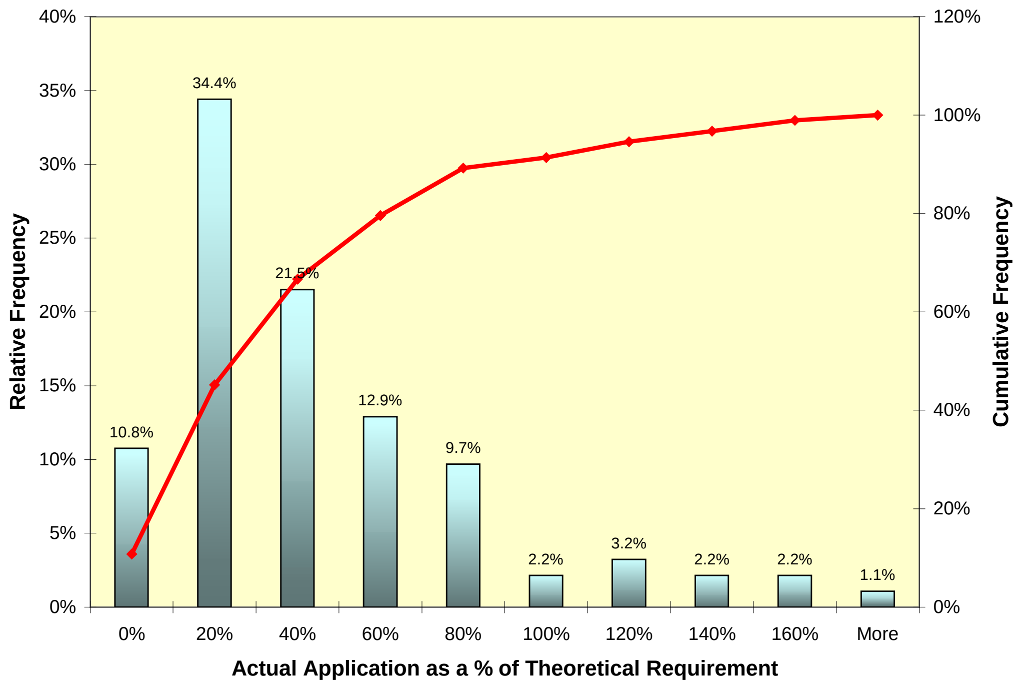


Figure 15: Frequency distribution of actual application as a percentage of theoretical requirement.

Outdoor use during the two-week logging period ranged from zero (no irrigation) to more than 22,000 gallons. The average actual outdoor use in the 83 homes that had some irrigation was 5,205 gallons or approximately 377 gallons per day, but the average theoretical requirement was much higher, averaging 15,912 gallons (1,137 gpd). The median actual irrigation use was 3,443 gallons (250 gpd) and the median theoretical requirement was 11,239 gallons (803 gpd).

Automatic and Manual Irrigation

By examining the irrigation flow patterns on the individual flow traces it was possible to identify homes using automatic timed irrigation, manual irrigation (hose dragging), manually operated in-ground valves, or a combination. For the homes that did not irrigate during the logging period it was not possible to determine the irrigation technology. Table 15 shows the percent of each type of irrigation technology found in the Denver sample. More than 50% of the sites that irrigated had an automatic system. About 31% of the sites irrigated manually. The number of zones at each automatic irrigation study site is presented in Appendix A.

Table 15: Irrigation method

Irrigation Method	# of Sites	% of Sites
Automatic only	29	31.2%
Manual only	29	31.2%
Both automatic and manual	22	23.7%
In ground w/manual valve operation (as reported on customer survey)	3	3.2%
Unknown	10	10.8%

Water use was compared by irrigation method. The homes with both automatic and manual irrigation were included in the "automatic" category for this analysis. The automatic irrigators used more than three times as much water as the manual irrigators on average. Because the automatic irrigators tended to have larger areas to irrigate their average application as a percent of theoretical was only twice as much as the manual irrigators. The small sample of manual in-ground irrigators use was comparable to the manual irrigators. These results are shown in Table 16. The manual irrigators applied 24.2% of the theoretical requirement on average and the automatic irrigators applied 50.9% on average. The manual irrigators used an average of 2,158 gallons (156 gpd) over the logging period while the automatic irrigators used 7,101 gallons (515 gpd) on average.

Table 16: Water use by irrigation method

Irrigation Method	Average Application as a Percent of Theoretical	Average Actual Application (gal.)
Manual	24.2%	2157.7
Automatic	50.9%	7100.6
Inground manual	23.2%	2441.1

Irrigation Findings

These results re-affirm findings in other studies in Colorado and around the country that indicate that homes with automatic sprinkler systems use significantly more water than homes that are manually irrigated. However, it must be noted that in Denver even the homes with automatic irrigation used substantially less than the theoretical requirement for their landscapes, suggesting that ET_o and the theoretical requirement is not a satisfactory target for irrigation efficiency. A percentage of ET_o – perhaps as low as 50 – 70% – is likely a better target to aim for. It is clear that healthy and attractive landscapes can be successfully maintained on a less than the full ET_o application depth. Appendix B provides a sample of three groups of home, the two homes that applied the highest percentage of theoretical ET during the irrigation season, two homes that applied an average amount, and two homes that applied no irrigation.

The REUWS report indicated that in 1996 these customers applied approximately 85% of ET to their landscapes. This was for the entire year, so it may be somewhat misleading to compare it to the irrigation just during the June/July period. However, this does indicate that irrigation use by the group has dropped since the REUWS data were collected.

Summary and Conclusions

The following points are some of the key findings of this research project.

- The study sample from the Residential End Uses of Water study remains representative of the Denver Water single-family detached customer base at least in terms of average annual water use.
- Average per household use decreased from 166 kgal to 105 kgal (37%) between 1994 and 2004. Both indoor and outdoor use decreased during this time period.
- The largest annual decrease in water use occurred in 2003, the second year of drought restrictions.
- Indoor use decreased by an average of 7 kgal (11%) per customer per year. Approximately 4% of this decrease is due to changes in demographics and 7% is due to efficient fixtures and appliances.
- Substantial indoor conservation potential remains. Indoor use reductions can (and likely will) be achieved by Denver Water's single-family customers in the coming 10 to 20 years.
- Outdoor use decreased by an average of 53% between 1994 and 2004. The largest decrease was observed in 2003.
- Some of the reductions in outdoor use are the result of drought restrictions and pricing measures. However, the declining trend in outdoor water use appears to be related to weather patterns as well.
- Prior to the drought of 2002 - 2004 these customers applied approximately 85% of net ET to their landscapes on average. In 2004, during the third year of drought restrictions and surcharges, these customers applied 55% of net ET.
- It is not clear is the observed reduction in irrigation application rates are durable or will gradually rise to pre-drought levels, but an analysis of the survey results suggests that a portion of these savings may be long lasting

Appendix A

Key-code	Total Irrig. Use (gal.)	Irrig. Meth od	# of Zones	Irrig. Area (ft^2)	Logged Days (6/1–7/25/05) Volume(gallons) 1	2	3	4	5	6	7	8	9	10	11	12	13	14
11005	190	M		5,250				91		51					48			
11014	4989	A	6	3,750								2410			2364			215
11015	7562	A	6	3,750	112	872	36		1345		1089		1258	117	70	1420		1243
11029	1117	M		2,814	161							526					431	
11032	60	M		3,798									39				20	
11034	2692	M		3,750	864					1238	590							
11035	17447	A	7	13,360	1849		115	1196	1242	1723		1480	649	3055	1549	1538	1509	1541
11037	6494	A	3	8,360	684		671	1790	697			1296		672		685		
11059	1841	M		5,698							962							880
11062	2061	IM	2	7,019	643			550	410							457		
11063	10984	A	6	3,750	13	2084	26	30	1733	164	1387	337	1773	229	992	1146	65	1005
11070	359	M		3,900	151						208							
11076	1139	A	7	8,960	300		143			174					107		274	141
11079	4618	A		3,444	798		758			761		798		752				751
11082	40	M		3,570	40													
11084	877	A	6	9,520						21	856							
11085	5038	A	6	9,120						2153	620	60		21			2186	
11092	1651	A	7	2,814		553							544			553		
11094	1782	M		7,738	124					1611				47				
11098	4887	A	4	6,312		1220				1213		1218						1236
11101	6240	A	3	2,622	731		725	729		719	38	972		729	739		724	134
11112	21321	A	14	17,760	66	2380			2013	1306	3112	1805	2193		293	4169		3985
11116	1606	M		1,554		370					373		474				69	321
11121	6322	A	9	3,750		1059			1056		1052		1061			1072		1022
11124	1066	B	4	1,872	286	20	28		26			192		9	156	348		
11135	6359	A	6	6,720		796	825		864	130			1017	845	825	136	850	70
11137	3312	B	2	15,000	304	416		562	152	21	195	1009	79	409			166	
11141	206	IM	1	10,800													160	47
11146	6883	A	4	3,711	2284		1109	36	1096		1121	58			22	47	1110	
11167	9092	B	7	8,256		1387		1209	1255		1248		1298			1233		1462
11175	3015	B	6	8,600	502		494			501		499		505			514	
11178	415	M		2,814						8		54		353				
11183	5056	IM		3,810		671			1197		825		655			1137		571
11186	919	M		3,024							919							
11187	6507	A		2,814	11			2018		1295		484		490	1728		482	
11208	1317	M		2,814						334	406	243	333					
11234	1904	M		3,600	64				431				486					922
11236	2744	A	6	7,434	963		970									811		
11239	196	M		3,750	45												150	
11243	1305	A	6	5,467								1305						
11245	9429	A	8	5,992	1574			1594		1567		1544			1569		1580	
11247	19913	A	10	76,666		2779			2782		3542		3716			3552		3543
11251	4133	B	7	4,504	641		624		635	275		651	14	655		638		
11253	2457	B	6	3,750						131	65	1030			130		1101	

Appendix A

					Logged Days (6/1–7/25/05) Volume(gallons)													
Key-code	**Total Irrig. Use (gal.)**	**Irrig. Meth od**	**# of Zones**	**Irrig. Area (ft^2)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
11256	2149	B	5	20,520							2149							
11258	126	M		7,265							104		22					
11263	809	M		2,340					156	188		432				33		
11265	7205	A		6,720	965			969		968		957	570	10	1804		963	
11266	1259	M		3,000		172	84	339	60	88	180		6			239	91	
11268	12283	A	5	6,430	1745		1790			1741		3506			1730		1772	
11269	582	M		5,740	13			5										565
11270	7409	B	7	4,949		1030		1039	862	867		524		1042		1027		1019
11271	998	M		15,252												998		
11281	22485	B	11	9,620		3228		2953		3243	3256	350	1740	3062	566	3338	213	533
11289	4865	M		7,003		818				483		1278	165	520		658	944	
11299	7356	M		3,960	1654	25	1918	22	24	1753	21	1772	32	25	27	28	24	30
11300	6065	B	3	2,814	810	1291	508					617	983			1703		154
11302	13121	B	5	4,140	11	1217	101	88	1439	55	1672	3243	1235		1433	1118		1509
11303	16741	M		8,677		2143			1417		659			2011	8977	1533		
11309	2783	B	4	3,750		424	84		862		864		549					
11312	10731	B	4	3,786		1875			1750	52	1756		1753	0	46	1743		1758
11319	9232	A	10	2,856	1209	107		1496		1306	108	1309		188	1831	258	1324	95
11326	2664	M		11,680	691					295		409		817				451
11329	12983	B	8	11,386	448	1202		130	1528	110	2293		1448	1043	400	1379		3002
11348	278	M		9,553						92		90						95
11352	9667	B	8	6,902	407	295	210	1428	355		1580	572	148	832	595	1044	1694	505
11353	3230	A	6	4,984	818					800		804					808	
11356	5417	A	8	8,160	2021				423			2079		113				780
11363	9775	A	15	10,080	3573				7	2649	915		2631					
11364	5930	B	6	8,101		1309	592		1167	151	88	47	788	46		827		915
11368	2603	B	6	8,114		237	364	95		101	144	218	387	116	365	191	385	
11372	425	M		3,600	425													
11382	455	M		6,482				120			140							195
11387	18314	B	7	6,482	2854		2785	230		2695	228		1395	2673	1304	129	4021	
11392	2930	B	8	5,124	81	420	465		426		82	914					460	82
11407	4813	A	4	5,880		681			703		698		1355			676		700
11417	9063	A	5	5,355		2595			1306		1294		1292			1281		1295
11420	4240	M		8,640	96	710	185	35		170		1454			394		273	925
11432	3443	B	3	2,814	594			593		783				96	680	63	635	
11448	6001	M		3,600	513	727	875	299			728	146	65	911	94	978	665	
11456	864	B	5	3,660							864							
11463	1339	M		4,719			421	95		351				51			422	
11465	3850	B	6	6,142			849	8	310	840	7	111		850	5	38	833	

Appendix B

Landscape Photos

High Use Homes

Key-code 11302, 165.2% of Theoretical ET

Key-code 11319, 143.2% of Theoretical ET

Study Average Use Homes

Key-code 11112, 53% of Theoretical ET

Key-code 11329, 52.6% of Theoretical ET

Homes with no irrigation

Key-code 11147, No Irrigation

Key-code 11459, No Irrigation